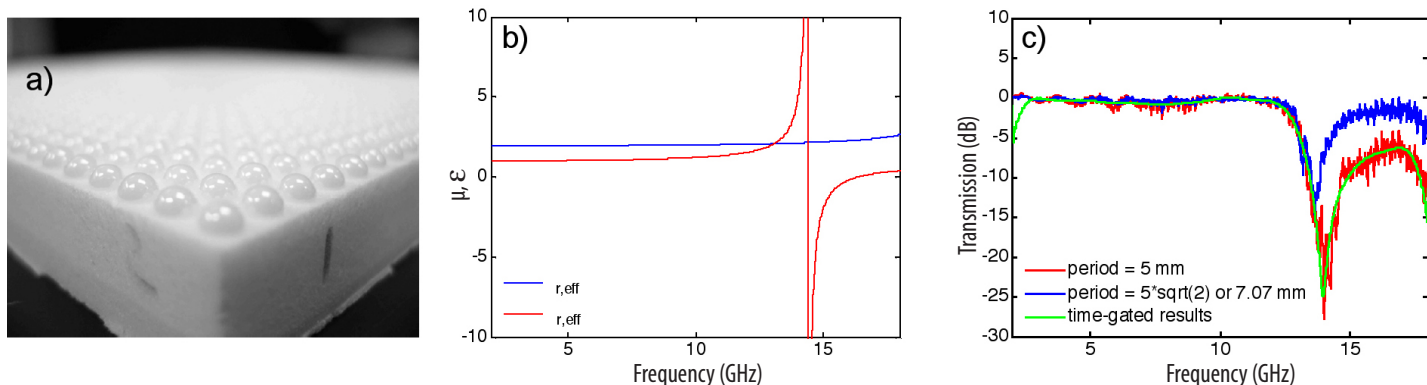


## Materials Science and Technology

### Optical materials

## Metamaterial Science and Technology



**Figure 1:** a) A photograph of a dielectric sphere-based RF metamaterial. b) Results of a numerical simulation of the effective electric permittivity and magnetic permeability of the array. Note the region of negative permeability just below 15 GHz. c) The measured RF transmission through the array. The observed stop band is in close correspondence with the predicted region of negative permeability.

*Sandia researchers are  
designing new structures  
that have unusual  
optical properties*

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**M**etamaterials form a new class of artificially-structured materials that provides the device designer with the ability to manipulate the flow of electromagnetic energy in ways that are not achievable with naturally-occurring substances. Recent theoretical investigations have predicted several astonishing applications, ranging from electromagnetic cloaking (rendering objects "invisible") to sub-diffraction limited imaging, that would become possible if the underlying metamaterials could be developed to a sufficient level. However, in spite of these and other advances in metamaterial theory, progress toward practical implementation, particularly at infrared and visible frequencies, has been hampered by high absorption losses. A large majority of the metamaterial designs demonstrated to date rely on the use of metallic structures and operate in the radio frequency (RF) range, where losses are significant but not insurmountable. However, as the frequency of operation is pushed towards the infrared and visible, ohmic losses quickly render current metamaterial approaches impractical.

Sandia has embarked on an ambitious research program to develop useful 3D metamaterials operating in the thermal infrared (8–12  $\mu\text{m}$ ). If successful, scientists will have the capability to arbitrarily engineer key optical material properties which will enable new optical designs and devices that can dramatically lower the size, weight, and power needed for national security and other applications. A top priority of this program is to reduce the absorption losses to levels suitable for device applications. This will require metamaterial designs that do not depend solely on metallic structures. One proposed approach is to utilize sub-wavelength arrays of dielectric resonator structures such as spheres (Reference 1). Through appropriate selection of the material and dimensions, resonators can be designed to exhibit either electric or magnetic dipole resonances at the desired operating frequency, thereby producing an effective electric permittivity or magnetic permeability that can be continuously tuned from positive to negative values. This approach can be readily verified through the design, fabrication, and characterization

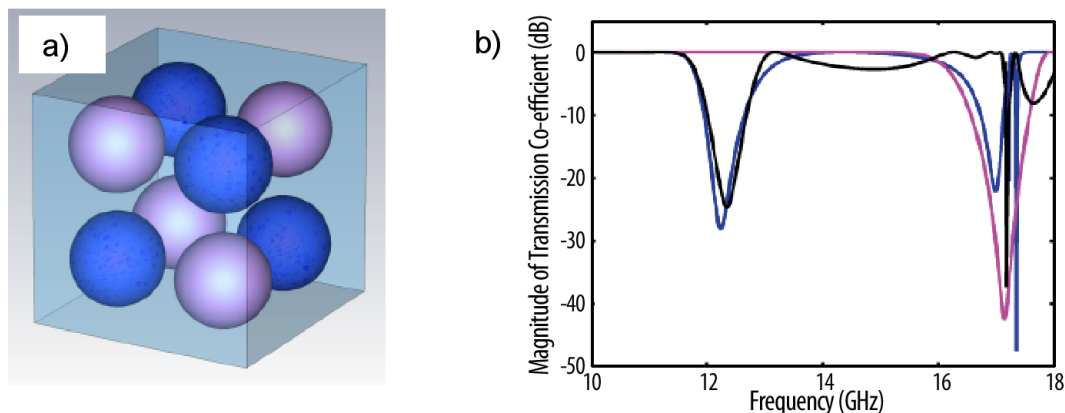
of metamaterials operating at RF frequencies, and then extended to the thermal infrared. As an initial test, several metamaterials operating in the RF have been developed. Figure 1a shows an array of 4 mm diameter zirconium dioxide ( $\text{ZrO}_2$ ) spheres ( $\epsilon_r=25$ ) contained in a computer-numerical-controlled machined RHOACELL® foam template. This array is designed to exhibit a magnetic dipole resonance near 14 GHz (Figure 1b). The measured RF transmission through the array (fig 1c) shows a deep transmission null near 14 GHz that corresponds to the spectral range where the effective magnetic permeability is negative.

In principle, simultaneous tuning of both the permittivity and permeability can be achieved through the use of a unit cell design that incorporates both electric and magnetic dipole resonators. To test this concept, Sandia researchers have designed (Reference 2) an isotropic, low-loss, negative index metamaterial, in which both the permeability and permittivity exhibit negative values at the RF operating frequency (Figure 2). The spheres colored in blue have a radius of 2 mm, and are designed to exhibit an electric dipole resonance near 17 GHz. The spheres colored in pink have the same radius, but are fabricated from a different material so

that they exhibit a magnetic dipole resonance at the same frequency. Because the spheres are arrayed with a sodium chloride (NaCl) cubic crystal structure, the response of the metamaterial is expected to be isotropic with respect to the direction of propagation of the electromagnetic wave. This metamaterial has been fabricated using spheres made from selected microwave ceramics and its RF transmission characteristics are currently being measured. Research is now focusing on preparing infrared metamaterials that employ the same concepts.

## References

1. C.L. Holloway, E.F. Kuester, J. Backer-Jarvis, and P. Kabos, "A double negative (DNG) composite medium composed of magnetodielectric spherical particles embedded in a matrix", IEEE Trans. on Antennas and Propagation, vol. 51, pp. 2596-2603, 2003.
2. J. H. Loui, J. Carroll, P. Clem and M. Sinclair, "Experimental realization of low-loss 3D isotropic DNG materials", proceedings of MM09, Sept. 2009, London, UK.



**Figure 2:** a) A metamaterial unit cell containing both electric (blue) and magnetic (pink) dipole resonators. The spheres are arrayed with the NaCl crystal structure to promote isotropic response. b) Results of a numerical simulation of the transmission through metamaterials containing only electric resonators (blue line), magnetic resonators (pink line), and the composite metamaterial containing both blue and pink spheres (black line). The region of high transmission near 17 GHz occurs where both the effective permittivity and permeability are negative and corresponds to a region of negative index behavior.